LCA Methodology

A Semi-Quantitative Method for the Impact Assessment of Emissions Within a Simplified Life Cycle Assessment

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Abstract. Intention, Goal and Scope: Dealing with data gaps, data asymmetries, and inconsistencies in life cycle inventories (LCI) is a general problem in Life Cycle Assessment (LCA) studies. An approach to deal with these difficulties is the simplification of LCA. A methodology that lowers the requirements for data quality (accuracy) for process emissions within a simplified LCA is introduced in this article. **Background:** Simplification is essential for applying LCA in the context of design for environment (DfE). The tool **euroMat** is a comprehensive DfE software tool that is based on a specific, simplified LCA approach, the Iterative Screening LCA (IS-LCA). Within the scope of the IS-LCA, there is a quantitative assessment of energy-related processes, as well as a semi-quantitative assessment of non-energy related emissions which supplement each other. **Objectives:** The semi-quantitative assessment, which is in the focus of this article, aims at lowering the requirements for the quality of non-energy related emissions data through combined use of qualitative and quantitative inventory data. **Methods:** Potential environmental impacts are assessed based on ABC-categories for qualities (harmfulness) of emissions and XYZ-categories for quantities of emitted substances. Employing statistical methods assignment rules for the ABC/XYZ-categories were derived from literature data and databases on emissions to air, water, and soil. Statistical tests as well as a DfE case study (comparing the materials aluminum and carbon fiber reinforced epoxy for a lightweight container to be used in an aerospace application) were conducted in order to evaluate the level of confidence and practicality of the proposed, simplified impact assessment. **Results:** Statistical and technical consistency checks show that the method bears a high level of confidence. Results obtained by the simplified assessment correlate to those of a detailed quantitative LCA. **Conclusions:** Therefore, the application of the ABC/XYZ-categories (together with the cumulative energy demand) can be considered a practical and consistent approach for determining the environmental significance of products when only incomplete emission data is available. **Future Prospects:** The statistical base of the method is expanded continuously since it is an integral part of the DfE software tool euroMat, which is currently being further developed. That should foster the application of the method. Outside DfE, the method should also be capable of facilitating simplified LCAs in general.

Keywords: ABC/XYZ-assessment; design for environment (DfE); emissions, simplified assessment; euroMat; impact assessment, semi-quantitative; Iterative Screening LCA (IS-LCA); Life Cycle Assessment (LCA), level of confidence; LCA results, statistical analysis of; simplified LCA; streamlined LCA

Introduction

Data collection is the most time-consuming task in Life Cycle Assessment (LCA) (Wenzel et al. 1997). Consequently, it is the most costly part of a study as well. Even though there have been several projects in order to set up and standardize life cycle inventory (LCI) databases (see, e.g. Bretz 1998a, Steen et al. 1995, Vigon 1996) data accessibility is still a serious problem (Bretz 1998b). One approach to deal with these difficulties is to decrease the requirements concerning data quality (accuracy) and data quantity (comprehensiveness of the inventory) through simplification of LCA (Fleischer et al. 1998a, Hunt et al. 1998, Rebitzer and Fleischer 2000, SETAC-Europe 1997, Todd 1996). This article presents a method for the assessment of non-energy related environmental impacts as part of a simplified LCA method that decreases the data requirements significantly (energy related impacts are represented by the screening indicator: cumulative energy demand – CED). This simplified LCA method is called Iterative Screening – LCA (IS-LCA) (Fleischer and Schmidt 1997, Klöpffer et al. 2000). However, the application of this impact assessment method is not limited to the IS-LCA, it can facilitate the impact assessment of simplified LCAs in general. In this article 'simplifying' is considered synonymous with 'streamlining' (as proposed by SETAC (SETAC-Europe 1997)).

The method intends to decrease the requirements for the quality of the processes' emission data. It is a semi-quantitative approach which uses evaluation categories for quantities and qualities (potential harmfulness) of emissions. It does not necessarily need exact quantitative LCI data to evaluate a product or service, best guess approaches and qualitative data as presented by SETAC (SETAC-Europe 1997, p. 22) can also be used very effectively. With the method in combination with the CED, it is possible to produce LCA results efficiently, but with a level of confidence high enough for many applications as e.g. design for environment (DfE). In this context, the level of confidence is defined as the probability of the simplified assessment producing an identical ranking of design options as the detailed LCA (Rebitzer 1999, p. 61).

After a brief presentation of the DfE method and software tool euroMat, of which the simplified LCA method is an integral part, the principles of the semi-quantitative impact assessment and the research to facilitate the applicability are presented. Finally, results of a case study for the validation of the method are presented.

1 Simplified LCA in the Design for Environment Tool euroMat

In the engineering design phase, the total environmental impacts caused by the production, use, and end-of-life treatment of a product are fixed to a high degree (Fleischer et al. 1997, Weckenmann and Schwan 1999). This is also true for the total costs (life cycle costs) associated with the life cycle (Ehrlenspiel et al. 1998, Siegwart and Senti 1995). For these reasons, product design tools that are capable of regarding potential environmental impacts, as well as life cycle costs in the early design stages, have to be employed. Within the research project 'Systematic Selection Criteria for the Development of Environmental Conscious Composite Materials' such a tool has been developed and is currently being implemented on a software basis. This DfE tool is called **euroMat** (Concurrent Engineering Design Tool for the Selection of Environmentally Sound and Recyclable Materials[1]). In principle, out of all existing materials (top-down approach), it is capable of identifying and assessing existing and not-yet existing materials (new combinations of materials) and the corresponding processes for material production, manufacturing, use, and end-of-life of the product. Presentations of the comprehensive features and methods of euroMat can be found in the literature (e.g. Fleischer et al. 1998b, Rebitzer et al. 2000).

[1] In German: euroMat – entwicklungsbegleitendes Instrument für umwelt und recyclingorientierte Materiallösungen

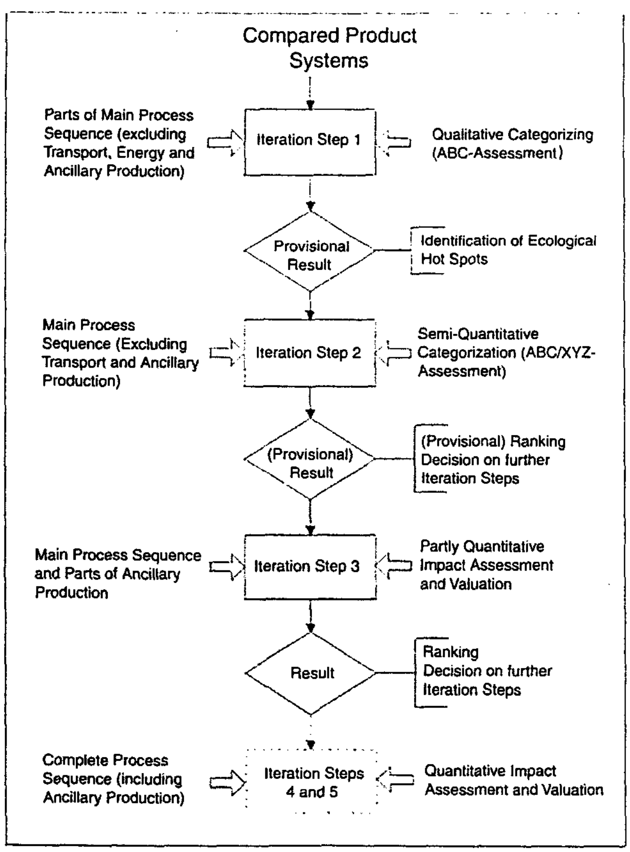


Fig. 1: Procedure of the Iterative Screening Life Cycle Assessment (IS-LCA) (Fleischer et al. 1998a)

Considering that euroMat is applied from the earliest stages of product development and that it looks at a huge number of material options, the procedures to deal with incomplete data, differing data quality, data asymmetries, and inconsistencies are of essential relevance for the tool. For the environmental assessment of material options, a simplified Life Cycle Assessment methodology, the Iterative Screening – LCA (IS-LCA) (Fleischer and Schmidt 1997, Klöpffer et al. 2000) is applied. In the IS-LCA the level of detail concerning the system boundaries, data qualities, inputs and outputs, and potential impacts to be included increases stepwise (see, Fig. 1). The level of confidence and thus the possibility to identify smaller differences in environmental performance of design options increases simultaneously from one iteration step to the next. The simplification of both the inventory and the impact assessment make it possible to produce LCA results very efficiently even when there is only little information on the product system available or if the system does not (yet) exist (assessment of a scenario). Rankings of material options from 15 case studies (11 of the case studies are presented by Fleischer et al. (2000), with which the IS-LCA has been tested, show a high level of confidence, with an increasing level of confidence with higher iteration steps (Braunmiller et al. 2000, Fleischer et al. 1998c).

In the following, the semi-quantitative impact assessment of non-energy related emissions, which is an integral element of the second iteration step of the IS-LCA, is presented in detail. It supplements the quantitative screening of potential environmental impacts from energy generation (cumulative energy demand (CED) according to VDI 4600 (VDI 4600 1997)). The usefulness of the CED as a screening indicator is not elaborated here, reasoning can be found in the literature (Braunmiller et al. 2000, Fleischer and Schmidt 1997, SETAC-Europe 1997).

2 Methodology of the Semi-Quantitative Impact Assessment

2.1 Principle approach

The semi-quantitative impact assessment method is a combination of an ABC-assessment for the identification of hot-spots (quality of emissions) and an XYZ-assessment, which is a measure for the quantity of a material flow between the observed product system and the environment (the natural environment as well as processes outside the system boundaries). In this terminology, an 'A' denotes serious environmental problems associated with an emission, whereas a 'C' indicates that a substance does not cause any significant problems. In the XYZ-assessment 'X' denotes a great, 'Y' a medium, and 'Z' an insignificant quantity. For each environmental medium (air, water, soil), an ABC/XYZ-categorization of an emission is performed. This semi-quantitative approach makes it possible to use both the available, detailed quantitative LCI data and qualitative information in the assessment, since both can be categorized in the ABC and XYZ-system. This eliminates data asymmetries and inconsistencies. The general concept of the ABC/XYZ-approach has been explained in detail by Fleischer and Schmidt and SETAC (Fleischer and Schmidt 1997, SETAC-Europe 1997).

The application procedure of the ABC/XYZ-assessment is as follows: To each emission (i.e. elementary flow which leaves the system), ABC/XYZ-scores for each of the three media are assigned. If emission data for an environmental medium are not available, the ABC/XYZ-scores are derived from expert judgment making it possible to use qualitative data together with quantitative data in the assessment method. In the next step, the most serious ABC/XYZ-score (the emission with the highest potential impact) is determined for each process and environmental medium. In the proposed scheme, the seriousness decreases in the following order: AX>AY=BX>AZ=BY>BZ>CX=CY=CZ. Each process is then characterized by the highest ABC/XYZ-scores for air, water, and soil. The process scores are aggregated over the complete life-cycle within the system boundaries using qualitative mass factors (mass factors give the relative share of the inputs and outputs of each process necessary to fulfill the functional unit, see Klöpffer et al. 2000). Finally, the scores across all three categories are aggregated for each product system using a weighting matrix as shown in **Table 1**. In this table, the air emissions are assigned a higher score because they are often deposited in water or soil later, possibly causing effects there as well. By sensitivity analysis, it was shown that the results of the assessment are not very sensitive to the choice of the weighting factors (e.g. the factors 0, 1, 10 yield equivalent results). The aggregated result – a one-score index for non-energy related emissions – is called AX_{air}-equivalent[2]. Together with the cumulative energy demand, this score serves as a measure to compare different materials in the second iteration step of euroMat (see e.g., Klöpffer et al. 2000).

Table 1: Aggregation matrix for the ABC/XYZ-scores (based on Klöpffer et al. 2000)

	Emissions to air			Emissions to water and soil		
	X_{air}	Y_{air}	Z_{air}	X	Y	Z
A	3	1	1/3	1	1/3	1/9
B	1	1/3	1/9	1/3	1/9	0
C	0	0	0	0	0	0

For the reliability[3] in general and the implementation in a software tool, which has become a standard requirement especially for simplified LCA methodologies (Rebitzer 1999, pp. 64), it is not feasible to perform the ABC/XYZ-assessment individually for each emitted substance on expert knowledge alone. The categorization has to be reasoned and made operational. Assignment rules for the quality (ABC, see, section 2.2) and quantity of emissions (XYZ, see, section 2.3) are necessary. These assignment rules are explained in the following.

[2] Actually, these equivalents should be called BY_{air}-equivalents, since BY_{air} has an weighting factor of 1. However, within this article, the established nomenclature to mark hot-spots (see, Klöpffer et al. 2000) is used

[3] Reliability: extent to which an experiment, test, or measuring procedure yields the same results on repeated trials (Webster's 1979)

2.2 Assignment rules for the quality of emissions (ABC-categorization)

Very different substances, with different environmental fates and impacts, different effect thresholds, etc. emitted from different processes have to be characterized as serious (A), relevant (B), or neglectful (C) emissions. To structure the assignment and to get relatively homogeneous categories, they are divided into subcategories. First, this subdivision is based on the kind of potential impacts of the emitted substances. This allows for the integration of aspects of detailed impact assessment methods. Well-researched impact categories or international classification criteria for toxic substances are used as far as possible. Secondly, subdivision criteria based on typical quantities of specific emissions have been defined. Table 2 shows the developed assignment rules for the ABC-categorization.

The subcategories do not present a further subdivision of the quality of emissions but intend to make substances within one category comparable, in order to make fairly narrow and specific quantitative XYZ-limits (see, section 2.3) possible. For instance, CO_2 (B2.2, contributing to global warming potential – GWP) and styrene (B1, toxic effects on humans through inhalation) are both categorized as 'B' (relevant environmental effects). Together with the XYZ-categorization (see, section 2.3), one can distinguish between a medium and a great amount of an emission. In this example, an emission to air of 0.6 g per kg of process product is considered a great amount (BX) or a medium amount (BY) for styrene or CO_2, respectively.

From Table 2, it is obvious that the semi-quantitative method is biased towards human and eco-toxicity. This is in line with the intention of the method since the 'classical' impact categories global warming, acidification, and eutrophication are represented by the screening factor cumulative energy demand to a high degree (SETAC-Europe 1997, p. 15). The intention of the ABC/XYZ-assessment is to account for the non-energy related 'hot-spots'. The categorization as shown in Table 2 is not finally fixed, it is detailed and revised continuously.

2.3 Assignment rules for the quantity of emissions (XYZ-categorization)

XYZ-categories are used to indicate the quantitative relevance of an emission. Within the second step of the IS-LCA, quantitative inventory data are not available for all processes and product systems. Available data are widely based on literature and significant differences in data quality exist. Experiences based on 15 DfE case studies conducted with euroMat show that only incomplete quantitative or semi-quantitative data on masses of emissions (great amount, medium amount, small amount, according to expert judgment) are available in most cases. Therefore, on the one hand, a systematic and consistent measure is necessary that defines the terms as being a great (X), medium (Y), or small (Z) amount. On the other hand, existing quantitative data have to be assigned to the XYZ-intervals in order to ensure data symmetry. The question becomes, "How does one classify an amount of an emission as great, medium, or small?". Obviously, limits setting the resulting intervals depend on

Table 2: Criteria for the assignment of non-energy related emissions to ABC-categories

	Group of substances	emitted to air		emitted to water		emitted to soil/waste	
		Criteria	**ABC-Cat.**	**Criteria**	**ABC-Cat.**	**Criteria**	**ABC-Cat.**
A	Carcinogenic, mutagenic, or teratogenic substances	Carcinogenic, mutagenic, or teratogenic (via inhalative intake)	S*:[A1.1] G*:[A1.2]	carcinogenic, mutagenic, or teratogenic(via oral intake)	S*:[A1.1] G*:[A1.2]	carcinogenic, mutagenic, or teratogenic (via inhalative or oral intake); no LCI data available	—
	very dangerous substances	Very toxic; toxic and persistent	S*:[A2.1] G*:[A2.2]	WGK 3 (strongly water threatening) and WGK 2 (water threatening)	[A2.2]	dangerous waste	[A2.2]
	other ecological hot spots	GWP>100/ ODP exists (substances with a high global warming and/or an existing ozone depletion potential)	[A3.1]	—		—	—
B	Dangerous substances	Xn (toxic), C (corrosive), allergenic substances	[B1]	WGK1 (low water threatening potential)	[B1]	(substances that can be transported within soil by water; available fraction); no LCI data available	—
	other substances with environmental importance	AP, NP exists; POCP exists; CO_2 and other substances with (GWP<100); toxic mixtures	[B2.1.1] [B2.1.2] [B2.2] [B2.3]	AP, NP exists; substances that can be degraded biologically (as COD, BOD, TOC)	[B2.1] [B2.2]	municipal solid waste and similar	[B2.3]
C	Substances without significant ecological importance (these substances are not observed within this article)						

[A#.#] ABC – subcategory
COD/BOD: Chemical /Biochemical Oxygen Demand within 5 days
TOC: Total Organic Carbon
WGK: Water Threatening Class (**Wassergefährungsklasse** as defined in (VwVwS 1996))
S*: single substances; G*: groups of substances and mixtures

the substance emitted. Therefore, limits for each ABC-category (see, section 2.2) must be defined.

25% and 75% quantiles[4] for the amounts of all emissions within one ABC-subcategory are proposed as limits for these intervals (i.e. the quantities of all emissions for one subcategory lower than the 25% quantile are characterized as 'Z', the quantities of all emissions higher than the 75% quantile as 'X') (Gerner 1999). The intervals have been defined using a huge database of inventory data for individual processes, including data from several studies and databases (see, APME 1992-1998, Ciroth 1998, Heyde and Kremer 1999, Nilson and Virtanen 1993, PRé 1997, Sutter et al. 1995). In the database, there is a big variation of data sources, levels of detail, and coverage of time, spatial considerations, and technology analyzed. The data mentioned above were selected because of their accessibility and their rather process-specific level of detail. The data are considered to be typical for data from literature and databases used in LCA studies. Only processes with a reference flow expressed as mass unit were used, since processes for energy generation are already included in the quantitative assessment of energy consumption (see, section 1). Transport processes are not included, because they are outside the scope of the system model of the second iteration step of the IS-LCA (see, Fig. 1). An extensive quality and consistency check was done during data handling. To avoid double counting, 81 processes were excluded from the database since they involve processes of energy transformation.

The final database includes 4332 material flows emitted by 339 processes (e.g. 'cellulose production by the sulfate process'). The emissions' data refer to 151 different substances[5] (e.g. 'ammonium to air' or 'chloride to water'). The regarded (industrial) processes belong to 16 different industrial branches covering a broad and representative range. Industrial branches were classified by the NACE-key of the European Community using the second level of classification (frequently reported branches are for example 'DG'-Chemical Industry). However, a comparison with the actual distribution of emissions in industry was not carried out because a suitable indicator for the environmental importance of industrial branches is not available.

Table 3 shows the derived limits for the XYZ-intervals for all ABC-categories (Gerner 1999). With these categories, quantitative data can be transformed into ABC/XYZ-intervals and experts' judgments can be facilitated by setting numbers on the terms 'great, medium, and small amounts'. This also ensures the reliability of the judgment, since objective metrics are used.

[4] Considering a sorted sample ($x_1, x_2, \ldots x_n$) of n values for a variable X, the quantile of the level p is the single value that is higher than p percent and lower than (1-p) percent of all values within the sample (Hartung et al. 1995). For example, the 25%-quartile of a sample is the value which is higher than or equal to 25% and lower than or equal to 75% of all values within the sample.

[5] The same substance emitted into different environmental media is counted as two different substances, since potential environmental effects may differ

Table 3: Limits of the XYZ-intervals for emissions (in gram of substance emitted per kilogram reference flow)

ABC-Sub-category*	Z-Interval (small amount)	Y-Interval (medium amount)	X-Interval (great amount)	Quantity of emission flows considered
Emissions to the air				
A.1.1	<0.0005	0,0005 - 5	>5	367
A1.2	<0.005	0.005 - 0.05	> 0.05	26**
A2.1	<0.00001	0.00001 - 0.005	>0.005	153
A2.2	<0.0005	0.0005 - 1	>1	110
A3.1	<0.001	0.001 - 0.05	>0.05	72
B1	<0.001	0.001 - 0.5	>0.5	157
B2.1.1	<0.05	0.05 - 2	>2	341
B2.1.2	<0.005	0.005 - 0.05	>0.05	361
B2.2	<10	10 - 2000	>2000	135
B2.3	<0.01	0.01 - 1	>1	171
Emissions to water				
A.1.1	<0.000,005	0.000,005 - 0.0005	>0.0005	301
A2.1	<0.000,01	0.000,01 - 0.005	0.005	564
A2.2	<0.000,01	0.000,01 - 0.001	>0.001	91
B1	<0.0001	0.0001-0.1	>0.1	711
B2.1	<0.1	0.1 - 15	>15	299
B2.2	<0.005	0.005 - 1.5	>1.5	241
Emissions to soil/ waste**				
A.2	<0,0005	0,0005 - 10	>10	123
B2.3	<0,1	0,1 - 50	>50	109

* see table 2 for the definition of the ABC categories
** Since no other direct emissions to soil were reported, within these categories only the final disposal of waste is considered

3 Critical Analysis of the Semi-Quantitative Method

In order to ensure a high level of confidence of the semi-quantitative assessment, a detailed statistical analysis of the emissions' database (see, section 2.3) was performed. The complete description of the analysis cannot be included in this article, therefore only the most prominent results are presented briefly. This is followed by the results of a case study analysis (see, section 3.2).

3.1 Statistical analysis of XYZ-categorization

The XYZ-intervals were analyzed by answering the following set of questions:

1. Is the number of emission values from the database (sample size) high enough to ensure the stability of the limits of the XYZ-intervals?
2. How are the LCI-emission values distributed and what causes for the distributions can be identified?
3. What influence do the criteria for the ABC-categories have on the XYZ-intervals?

The LCI emissions' data used for the definition of the XYZ-intervals are only a sample of all possible values. As a first attempt for the evaluation of the sample size, the condition $n > 48$ (n: sample size) is used. This condition is based on the statistical rule of thumb for estimating the necessary sample size for a given quantile: $\{p(1-p)n>9\}$ (Hartung et al. 1995). If $p = 0.25$ or $p = 0.75$ is used, $n > 48$ results. Therefore, when the sample size is greater than 48 and the sample consists of random values, quantiles can be calculated without considering the theoretical distribution of data. This condition is met for all ABC-subcategories, except for the group A1.2 (carcinogenic mixtures, see, Table 2), which require additional data to foster the methodology.

By uncertainty analysis, the stability of the XYZ-limits was analyzed further. Confidence intervals for the quantiles were calculated. The results are shown in Fig. 2. A small confidence interval indicates that the calculated quantile is very close to the real quantile of all possible data. A probability of 80% was used here. The confidence intervals can be considered rather small; as could be expected, groups of substances and

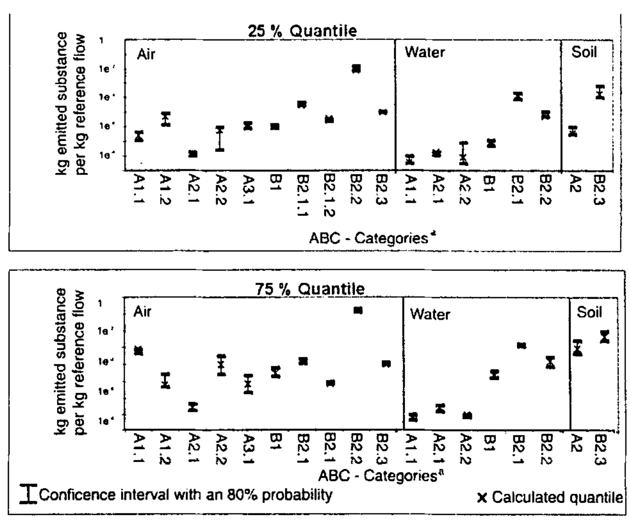


Fig. 2: Confidence intervals for the ABC-subcategories for 25% and 75% quantiles of the emissions data from the analyzed database. The calculation is based on a probability of 80% for the confidence interval

mixtures (A1.2, A2.2, A3.1, see, Table 2) show the biggest deviations. There is no significant difference between the confidence intervals of the 25% and the 75% quantiles. These results confirm that the number of emission values in the database is high enough to define the XYZ-intervals.

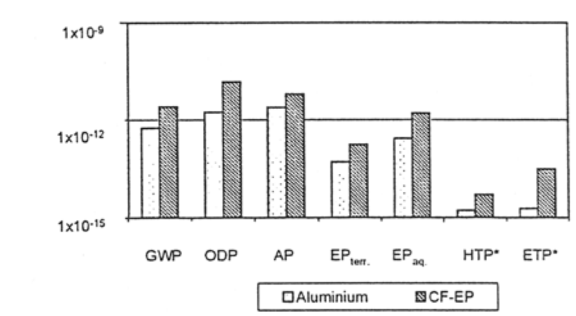
Distribution analysis was used to get an initial impression of the complete structure of the database and of the subsamples of emissions data for substances within each ABC-category. The specific point of interest here is that the number of emissions data needed to calculate stable quantiles could be reduced and statistical methods could be applied, if the data followed a theoretical distribution. In this case, however, the emissions data from the database cannot be described by any common theoretical distribution (normal and lognormal distributions were tested), neither for any of the examined ABC-categories nor for all data together. Further optimization was not possible at this point. However, the definition of the limits of intervals by quantiles seems to be an adequate method because quantiles are calculated based on sorted sets of data from a sample. Theoretical distributions do not have to be known if the sample size is big enough (see above).

XYZ-intervals are defined for the emission values of substances within one ABC-subcategory. Therefore, they do not depend solely on the quantitative LCI data, but also on the criteria for the ABC-categories and subcategories. A cluster analysis showed that even a classification of substances by pure statistical means, without taking into account the environmental effects of a substance, would not lead to more homogeneous groups of substances. Consequently, by statistical standards, the ABC-categorization does not affect the XYZ-intervals significantly.

Of course, the database used for categorization does not contain the complete knowledge on LCI data published today. However, it may be considered as a good starting point because the database is integrated in the software tool euroMat (see, section 1) and can easily be expanded. Therefore, XYZ-intervals can be adapted quite efficiently, taking new data into account. Additionally, however, XYZ-intervals should be reviewed when new knowledge on potential environmental impacts caused by a substance leads to a new ABC-categorization.

3.2 Case study analysis of the ABC/XYZ-assessment

The ABC/XYZ-assessment was applied to a DfE case study in order to validate its level of confidence and practicality. For this validation, a cradle-to-gate comparison of non-energy related emissions from the production of a lightweight container for the aerospace industry from the two material options aluminum and carbon fiber reinforced epoxy (CF-EP, 60% fiber content) was carried out. A container with a volume of 0.216 m^3 was used as a functional unit, leading to reference flows of 14.0 kg aluminum and 9.5 kg CF-EP. It has to be stressed that the comparison is only based on the semi-quantitative assessment of emissions and that only one element of the life cycle is considered. In order to perform a complete assessment of the environmental relevance of a system in the second step of the Iterative Screening-LCA, the complete life cycle has to be taken into account and the



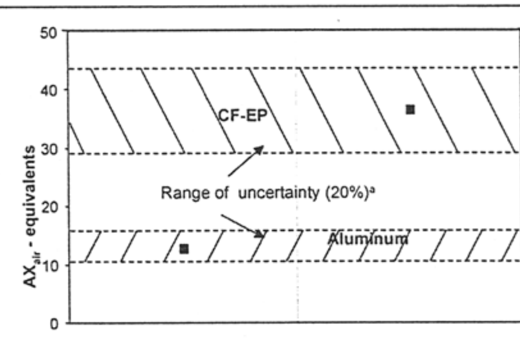
* Preliminary results for these categories

Fig. 3: LCIA results for the case study of five impact categories assessing non-energy related emissions (normalized): Comparison of a container with 14.0 kg aluminum or 9.5 kg carbon fiber reinforced epoxy (CF-EP) in a cradle-to-gate approach

cumulative energy demand has to be considered additionally. However, for purposes of validation of the semi-quantitative methodology concentrating on just the non-energy related emissions is adequate.

The database described in section 2.3 provided the base data, comprising detailed quantitative process data for both systems of the case study. With these data, a complete cradle-to-gate Life Cycle Inventory (LCI) and a Life Cycle Impact Assessment (LCIA) of the non-energy related processes of the two systems was performed. The resulting GWP, ozone depletion (ODP), acidification (AP), terrestrial and aquatic eutrophication (EP), human toxicity (HTP), and eco-toxicity potential (ETP) were determined. The potentials were normalized within each category. The results of this assessment, which are shown in **Fig. 3**, serve as the reference for determining the level of confidence of the semi-quantitative assessment as defined in the introduction.

Using the same process data, the emissions data were converted into ABC/XYZ-categories as explained in section 2. The ABC/XYZ-values were aggregated using mass factors based on the reference flows and on qualitative mass factors (see, section 2.1). **Fig. 4** shows the calculated AX_{air}-equiva-



a ABC-categories and XYZ-mass intervals, according to **Table 2** and **3**.

Fig. 4: Case study results for the semi-quantitative assessment of non-energy related emissions based on AX_{air}-equivalents: Comparison of a container with 14.0 kg aluminum or 9.5 kg carbon fiber reinforced epoxy (CF-EP) in a cradle-to-gate approach

lents per functional unit for both material options, taking an estimated 20% uncertainty into account.

Both evaluation methods – the simplified semi-quantitative and the quantitative LCIA – lead to the same ranking result: aluminum has a lower environmental impact than the composite. Also, the relative differences identified by the quantitative and semi-quantitative approach correlate to a certain degree. This suggests that smaller differences in environmental performance of systems can also be identified using the simplified method. The case study indicates that the simplified method estimates the environmental impacts of emissions adequately (in the context of DfE). Other studies within the euroMat project confirm these findings.

4 Conclusions and Outlook

Within the scope of simplified LCA, the semi-quantitative impact assessment based on ABC/XYZ-assignment rules as introduced in this paper is a practical method for the estimation of the environmental impact of a product system when only qualitative or incomplete quantitative LCI data for all or some of the involved processes are known. The statistical analysis and the design for environment (DfE) case study presented, as well as other studies, indicate that the results of the method are reliable and that they have a relatively high level of confidence. A comprehensive statistical analysis based on a big LCI database shows the robustness of the proposed assignment rules. The case study confirms that the semi-quantitative method leads to a similar ranking of material alternatives as a detailed impact assessment.

Considering the generally high number of material options and the necessity to get a quick answer in a DfE process, the ABC/XYZ-assessment is an adequate procedure for assessing and comparing design options in combination with the cumulative energy demand. However, the assignment rules have to be reviewed and adapted in the future in order to update the values for the XYZ-intervals used in the method. This should be done continuously as new LCI data are to be integrated.

The application of the developed method does not have to be limited to DfE. Most LCA studies have to deal with data gaps, data asymmetries, and inconsistencies (Bretz 1998b). In these cases, this semi-quantitative method may facilitate the impact assessment as well.

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Note Added in Proof: Further Development and Application of the DfE Software Tool euroMat

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The development of DfE tool euroMat that includes the semi-quantitative impact assessment method as described in the article has been progressing rapidly. The procedures for technology-based material selection including the identification of feasible manufacturing and recycling processes as well as the Iterative Screening LCA have been developed into a software prototype. Currently, software modules for Life Cycle Costing, work environment, and risk assessments are being integrated. In parallel, the methodology and tool was tested in depth within four industrial case studies (see Fig. 1-4). Beginning in spring 2001, the development of a software product of the euroMat tool based on the prototype is envisaged. **Fig. 1:** Front subframe system for a middle class passenger automobile (Ford Werke AG). **Fig. 2:** Freshwater tank for an Airbus passenger aircraft (MAN Technologie AG). **Fig. 3:** Door panel for a lightweight truck (Sachsenring Enwicklungs GmbH). **Fig. 4:** Rotational moulding tool (Denios AG).

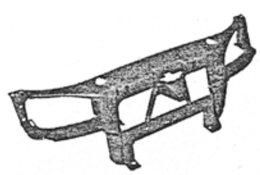

Fig. 1: Front subframe system

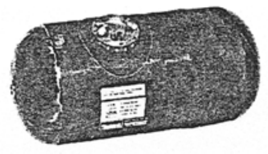

Fig. 2: Airbus freshwater tank

Fig. 3: Door panel for lightweight truck

Fig. 4: Rotational moulding tool

For further information on opportunities for the implementation of euroMat within your organization, please contact:
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